APPENDIX F

SUBSURFACE HYDROLOGY*

F.1 REGIONAL HYDROGEOLOGY

F.1.1 Regional geology and physiography

The Savannah River Plant (SRP) is located in the Upper Atlantic Coastal Plain, about 40 km southeast of the Fall Line, which separates the Piedmont and Coastal Plain provinces (Figure F-1). The coastal plain is underlain by a wedge of seaward-dipping unconsolidated and semiconsolidated sediments which increase in thickness from zero at the Fall Line to greater than 950 meters near the coast of South Carolina (Rankin, 1977) and continues to the seaward edge of the Continental Shelf. The topographic surface of the coastal plain slopes gently seaward as do the geologic units underlying this surface.

The Savannah River Plant lies on the Aiken Plateau as defined by Cooke (1936). The Aiken Plateau is bounded by the Savannah and Congaree Rivers (Figure F-1), and slopes from an elevation of 200 meters (above mean sea level) at the Fall Line to an elevation of about 76 meters. The surface of the Aiken Plateau is highly dissected and is characterized by broad interfluvial areas with narrow steep-sided valleys. Relief is locally as much as 90 meters (Siple, 1967). The Plateau is generally well drained although small poorly drained depressions occur. Drainage is poor in the low-lying river swamp areas.

The Savannah and Congaree Rivers are the largest in the region. The Savannah River forms the boundary between South Carolina and Georgia. The river has a flood plain 6 to 8 kilometers wide downstream from Augusta, Georgia, and a stream gradient of about 1.9×10^{-4} adjacent to the Savannah River Plant.

Between the Savannah and the Congaree Rivers are the North and South Forks of the Edisto River and the Salkehatchie River. Both of these rivers originate on the coastal plain and flow southeastward into the Atlantic Ocean. These rivers do not incise their valleys as deeply into the sediments as do the Savannah and Congaree Rivers. On the Aiken Plateau there are several southwest flowing tributaries to the Savannah River. From the Fall Line these are Horse Creek, Hollow Creek, Upper Three Runs Creek, Four Mile Creek, Pen Branch, Steel Creek, and Lower Three Runs Creek (Figure F-2).

The sediments of the Atlantic Coastal Plain in South Carolina are stratified gravel, sand, clay, and limestone which dip gently seaward; there are local variations in dip and thickness due to locally variable depositional regimes. The base of the coastal plain sediments lies on the weathered surface of the crystalline metamorphic rock that dips at a gradient of about 6.8×10^{-3} from the Fall Line. Imbedded in the crystalline metamorphic rock is at least one |TC
sedimentary basin of Triassic age. The basin is comprised of sedimentary rocks that are buff to maroon in color and contain poorly sorted sands and clays.

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*This appendix is developed primarily from Du Pont (1983).

The erosional surface on the crystalline metamorphic rock is continuous across the Triassic basin and has a very low relief.

The structural setting of the Atlantic Coastal Plain is a monoclinal dip of gradient 1.7×10^{-3} to 6.8×10^{-3} to the southeast with some local variations. The Triassic basins beneath the coastal plain were created by tensional rifting and erosion from fault block mountains and deposition into fault block valleys, much as is occurring today in the basin and range province of Utah and Nevada.

F.1.2 Regional hydrology

Water moves through the ground from areas of high potential energy (the combined elevation and pressure heads) to areas of lower energy. In general, on the Atlantic Coastal Plain, this involves ground water moving seaward from the higher areas of the Aiken Plateau toward the Continental Shelf. Because most sedimentary units become finer grained and less transmissive toward the coast, this movement becomes exceedingly slow. Of major significance is the modification from this general southeastward movement caused by the incision of the Savannah and Congaree Rivers. Ground water in the regions of these rivers flows toward the hydraulic-energy low caused by discharge to the surface in these river valleys. Savannah River Plant is totally on the Savannah River side of the ground-water divide that occurs between these two rivers. Thus, the regional ground water of interest will have directions of flow determined by the relationship of the ground water to the Savannah River Valley.

The depth of dissection by the southwestward-flowing tributaries has a significant influence on the direction of flow in most hydrostratigraphic units. In general, the direction of flow in the shallow ground water is most affected by small tributaries, deeper ground water by major tributaries, and deepest ground water only by the Savannah River itself. It is not unusual to have the deepest ground water moving at right angles, or even in the opposite direction to the shallow ground water at a particular location because of differences in stream incision.

The depth to the water table (the beginning of the saturated zone, below which all pores are filled with water and above which pores are partially filled with air) ranges from zero to about 38 meters below the surface. The depth to the water table is dependent on the horizontal and vertical hydraulic conductivity, topographic drainage and local surface water conditions. In some places where interbedded clays are common, the vertical movement of water is impeded and shallow or locally perched water tables exist. In other places where these clays are not present, the water table may be very deep. The water table generally slopes in the same direction but more gently than the land surface. Thus, deeper water tables commonly exist near the cuesta face of the asymmetrical tributary creek valleys, that is, the southeast side of the valleys; whereas shallower water tables exist on the northwest side.

As used in this appendix, the SRP vicinity extends only to those distances that could have a cause-effect relationship to ground water at Savannah River Plant. This distance ranges from about 64 kilometers from the center of the plant in a northerly direction to about 32 kilometers in a southeasterly direction. Even though the geologic names used for some of the water-bearing units at SRP extend to great distances, the hydrologic relationships do not. Thus, the hydrologic region is much more restricted than the geologic region.

The coastal plain sediments constitute a multilayer hydrologic system in which there are both retarding and transmitting beds, so that parts of it may be somewhat hydrologically isolated from other parts. Hydraulic properties vary for each of the hydrostratigraphic units, depending on their lithology. Groundwater flow paths and flow velocities for each of these units are governed by the hydraulic properties, by the geometry of the particular unit, and by the distribution of recharge and discharge areas.

Because of the sandy nature of the sediments and the comparatively short residence time of ground water (centuries), the water in the coastal plain sediments is low in dissolved solids. Most of the waters have a low pH (about 5.5) and are generally corrosive to metal surfaces.

F.1.3 Formation terminology

In order to discuss the geology and hydrology of the region and of the Savannah River Plant specifically, it is convenient to designate parts of the geologic column with names. Historically, the criteria for designating geologic units with names is well established, but in practical application, this topic is sometimes confusing. Ideally, each geologic unit should have a set of physical and visually observable characteristics that distinguish it from other units in the area. When a geologic unit has such a set of characteristics and is thick enough and extensive enough to be shown on the usual scale of geologic mapping, it is called a "formation" and receives a formal name. These names are designated and accepted through publication in the open refereed literature according to certain rules.

The terminology for the hydrostratigraphic units used in this report (Table F-1) is modified from that used by Siple (1967). Table F-1 describes the lithology and water-bearing characteristics of these units. These terms, as modified, have been found very useful in numerous studies of ground water at the SRP. Figure F-3 is a cross section through SRP from the Fall Line showing the relationship of the units discussed in Table F-1. Figure F-4 shows a tentative correlation of these units to stratigraphic terminology being described in current publications. However, the thrust of much of this current literature is on biostratigraphy and regional correlation of mappable units and not on hydrostratigraphy. Thus, for purposes of this appendix, the older terminology is retained.

F.1.4 Water-level measurements

Water levels used to construct piezometric maps presented in this appendix were measured in monitoring wells (not in pumping wells) during normal plant operations, including the withdrawal of process and domestic water from groundwater sources. EL-24

F.2 DESCRIPTION OF THE HYDROSTRATIGRAPHIC UNITS

Three distinct geologic and hydrologic systems exist in the SRP vicinity (Figure F-3):

- The coastal plain sediments where water occurs in porous, unconsolidated to semiconsolidated sands and clays

- The buried crystalline metamorphic basement rock consisting of chlorite-hornblende schist, hornblende gneiss, and lesser amounts of quartzites, where water occurs in small fractures

- A buried Triassic basin consisting mostly of red consolidated mudstone with some poorly sorted sandstones, where water occurs in the intergranular space but is very restricted in movement by the extremely low permeability

Figure F-5 shows the depth and thickness of the hydrostratigraphic units in the coastal plain sediments and the water levels associated with each unit near the center of SRP (H-Area).

F.2.1 Crystalline metamorphic rock

Near the center of SRP the crystalline and metamorphic rock is buried beneath about 280 meters of unconsolidated-to-semiconsolidated coastal plain sediments (Marine, 1967). The surface of the rock dips to the southeast at a gradient of about 6.8×10^{-3} (Siple, 1967), and the rock crops out at the Fall Line about 40 kilometers northwest of SRP.

Water injection and removal tests on packed-off sections of rock indicate that there are two types of fractures in the crystalline rock (Marine, 1966). The first type consists of minute fractures that pervade the entire rock mass but transmit water extremely slowly. Rock that contains only this type of fracture is called "virtually impermeable rock." The other type of fracture is restricted to definite zones that are vertically restricted but laterally correlatable and have larger openings that transmit water faster. Rock that includes this type of fracture is called "hydraulically transmissive rock."

Representative values of the hydraulic conductivity are 1.2×10^{-2} liters per day per square meter for virtually impermeable rock and 33 liters per day per square meter for hydraulically transmissive rock (Marine, 1975). Analysis of a two-well tracer test with tritium indicated a fracture porosity of 0.08 percent in a hydraulically transmissive fracture zone (Webster et al., 1970). Laboratory analyses of cores indicated an average intergranular porosity of 0.13 percent.

Immediately overlying the crystalline rock is a layer of clay (saprolite), which is the résidual product of weathering of the crystalline rock. The combined saprolite and basal-Tuscaloosa clay (Figure F-5) at the top of the metamorphic rock form an effective seal that separates water in the coastal plain sediments from water in the crystalline metamorphic rock.

Except for testing programs, there is no pumpage from the metamorphic rock until the Fall Line is approached. From there westward in the Piedmont Province, the metamorphic rock provides water for domestic use. Because of the prolific aquifer in the overlying coastal plain sediments and the saprolite/clay seal, it is unlikely that the hydrologic regimen of the metamorphic rock will be impacted by Savannah River Plant in this area.

Table F-2 shows a typical chemical analysis of water from the crystalline metamorphic rock. The water has a total dissolved solids content of about 6,000 milligrams per liter, which is largely calcium (500 milligrams per liter), sodium (1,300 milligrams per liter), sulfate (2,500 milligrams per liter), and chloride (1,100 milligrams per liter).

F.2.2 Triassic sedimentary rock

A groben-like basin of mudstone (the Dunbarton Basin), formed by downfaulting of the crystalline metamorphic rock during the Triassic Period, is buried beneath about 370 meters of coastal plain sediments (Figure F-3). The northwest boundary of the basin has been well defined by seismic traverses and by a well that penetrated 490 meters of Triassic rock and then passed into the crystalline metamorphic rock below. The southeast margin is not as well defined because there is no well similarly placed to the one that defines the northwest margin (Marine, 1976a).

The upper surface of the Triassic rock is beveled by the same erosional cycle that created a peneplain on the crystalline rock surface. This surface is now tilted at a gradient of about 6.8×10^{-3} (Siple, 1967), but after correct- |TC
ing for this dip, the surface is extremely flat and featureless.

The depth to the bottom of the Dunbarton Basin is not known from well penetration except along the northwest border. A well near the center of the basin was drilled to a depth of 1,300 meters and did not penetrate crystalline rock.

The Triassic sediments consist of poorly sorted, consolidated gravel, sand, silt, and clay. The coarser material is found near the northwest margin where fanglomerates are abundant. Nearer the center, sand, silt, and clay predominate; however, the sorting is always extremely poor (Marine and Siple, 1974), which causes an extremely low primary permeability in the Triassic rocks. Ground water occurs in the primary porosity of the Triassic clastic rock. However, the hydraulic conductivity is extremely low, and water movement is almost nonexistent.

The hydraulic conductivity of the Triassic sedimentary rock as determined from field tests ranged from 4×10^{-3} to 4×10^{-6} liters per day per square meter (Marine, 1974). The average total porosity was 8.0 percent for sandstones and 3.3 percent for mudstones. The average effective porosity was 7.0 percent for sandstones and 0.53 percent for mudstones.

Table F-2 lists some chemical analyses of water samples from the Dunbarton Basin of Triassic age. Samples from the deeper wells (DRB 10 and DRB 11) near the center of the basin had total dissolved solids contents (almost entirely sodium chloride) of 12,000 and 18,000 milligrams per liter.

No water is pumped from the Dunbarton Triassic Basin, nor is there likely to be in the future because of the poor water quality and the low permeability of the rocks.

F.2.3 Tuscaloosa Formation

F.2.3.1 Hydrostratigraphy

The Tuscaloosa Formation consists primarily of fluvial and estuarine deposits of cross-bedded sand and gravel with lenses of silt and clay. It rests directly on saprolite, a residual clay weathered from the crystalline metamorphic rock. The Tuscaloosa is overlain conformably by the Ellenton Formation, but near the Fall Line, where the Ellenton is absent, it is overlain unconformably by sediments of Tertiary and Quaternary age (Siple, 1967). The Tuscaloosa crops out in a belt that extends from Western Tennessee to North Carolina. In South Carolina, this belt is from 15 to 50 kilometers wide. The thickness of the Tuscaloosa ranges from zero at the Fall Line to about 230 meters beneath the L-Reactor site at Savannah River Plant (Figure F-3). The thickness remains fairly constant in the SRP area.

In this region, the Tuscaloosa consists of light gray to white, tan, and buff colored cross-bedded quartzitic to arkosic coarse sand and gravel, with lenses of white, pink, red, brown, and purple silt and clay (Siple, 1967). Ferruginous sandstone concretions, siderite nodules, and lenses of kaolin 0.5 to 12 meters thick are present in the Tuscaloosa. The chief minerals in the sediments are quartz, feldspar, and mica, which were derived from weathering of the igneous and metamorphic rocks of the Piedmont province to the northwest.

In areas of the South Carolina Coastal Plain within about 40 kilometers of the Fall Line, sand beds in the Tuscaloosa Formation form one of the major supplies of ground water. Industrial wells in this aquifer commonly yield more than 3,800 liters per minute of good quality water.

The Tuscaloosa Formation is the thickest (170-250 meters) of the coastal plain formations in this area (Figures F-3 and F-5). Near the center of the SRP area, the units of the Tuscaloosa Formation from top to bottom (Figure F-5) are (1) a unit of clay, sandy clay, or clayey sand about 20 meters thick; (2) an aquifer unit of well-sorted medium to coarse sand about 45 meters thick; (3) a unit, about 12 meters thick, in which one or more clay lenses occur; (4) an aquifer unit of well-sorted medium-to-coarse sand about 90 meters thick; and (5) a basal unit of sandy clay about 12 meters thick. The two aquifer units (2 and 4) combined are about 135 meters thick and are used singly and together to supply water-production wells at SRP. For many purposes, they are treated as one aquifer; however, they are hydraulically separated at Savannah River Plant, except near wells that take water from both units.

F.2.3.2 Hydrologic characteristics

Field tests of the transmissivity of the Tuscaloosa Formation were made when the original wells were drilled during the construction of Savannah River Plant (Siple, 1967). A representative value of transmissivity is listed in Table F-3 for each area at Savannah River Plant shown on Figure F-6 (Marine and Routt, 1975). The average of these 11 transmissivity values is 1.5×10^6 liters per day per square meter; the median is 1.4×10^6 liters per day per square meter. Storage coefficients were determined for seven regions of the Tuscaloosa Formation (Siple, 1967); the average value is 4.5×10^{-4}. Effective porosities were reasonably assumed to be 20 percent to 30 percent (Siple, 1967).

The location of Savannah River Plant and the outcrop area of the Tuscaloosa Formation are shown together with a piezometric map of the formation in Figure F-7. Where the outcrop area is high in elevation, such as on the Aiken Plateau in the northeast sector (Figure F-7), water recharged to the Tuscaloosa Formation exceeds the water discharged to local streams, and this excess water moves southeastward through the aquifer. Where the outcrop area is low in elevation, such as along the Savannah River Valley in the northwest sector (Figure F-7), water discharges from the formation to the river. Thus, the pattern of flow is arcuate.

Recently (1982) two independent piezometric maps of the Tuscaloosa aquifer have been published. The first of these (Figure F-8) was prepared by Faye and Prowell (1982) based on data from 1945 to 1981. The general piezometric pattern presented on this map is the same as that presented by Siple (1967), and the map shows an arcuate flow pattern toward a sink along the Savannah River. Another piezometric map of the Tuscaloosa Formation was prepared in a study for Georgia Power Company (1982) using only data from May to June 1982. This map (see Figure F-32) also shows a ground-water sink along the Savannah River. All of these maps indicate that ground water in the Tuscaloosa Formation does not cross from South Carolina into Georgia or from Georgia into South Carolina.

The term "Tuscaloosa Formation" has been applied to geologic deposits from North Carolina to Louisiana. This formation is a prolific aquifer in parts of North Carolina, South Carolina, and Georgia. However, the water in the formation that passes beneath Savannah River Plant recharges and discharges from the formation only in Aiken, Barnwell, and Allendale Counties of South Carolina. In general, these three piezometric maps do not distinguish between wells in upper and deeper aquifers of the Tuscaloosa Formation; yet it is known at Savannah River Plant that wells screened near the base of the lower Tuscaloosa that are away from centers of pumpage have a higher water level than those in the upper part of the Tuscaloosa. Figure F-9 is a piezometric map of the Tuscaloosa aquifer on Savannah River Plant. Water-level data from wells screened only at the bottom of the aquifer were not used. Although the data for this map are sparse, flow in the Tuscaloosa toward the Savannah River is confirmed.

The relationship of water levels in the Tuscaloosa Formation to those in overlying formations at H-Area in 1972 is shown in Figure F-5. The head in the upper Tuscaloosa is about 1.2 to 1.8 meters above those in the Congaree; however, these particular Tuscaloosa observation wells are within the influence of the cone of depression caused by the continuous pumpage from nearby wells in H-Area. A single water-level measurement in the Tuscaloosa in 1952, before pumping began, indicates a head difference in H-Area 2 meters greater than that measured in 1972. | TC

Table F-3. Transmissivity of the Tuscaloosa Formation (Area locations shown on Figure F-6)[a]

Location	Transmissivity ℓ/day/m
Savannah River Plant	
A-Area	1.2×10^6
C-Area	1.4×10^6
F-Area	2.5×10^6
H-Area	2.5×10^6
K-Area	1.4×10^6
L-Area	8.7×10^5
P-Area	6.2×10^5
R-Area	1.1×10^6
Aiken	1.2×10^6
Williston	1.5×10^6
Barnwell Nuclear Fuel Plant	1.8×10^6
Average	1.5×10^6
Median	1.4×10^6

[a]Adapted from Marine and Routt (1975).

In addition to showing more detailed stratigraphy at Savannah River Plant, Figure F-5 also shows that the water head in the coastal plain formations in the vicinity of H-Area generally decreases with increasing depth down to the Congaree Formation. This trend indicates some downward movement of water in addition to its horizontal movement. The Congaree Formation crops out in the more deeply incised stream valleys on the plant site, and the water head in this aquifer is controlled in part by the elevation of these on-plant streams. The water head in the Tuscaloosa and Ellenton Formations is higher than in the Congaree Formation (Figure F-5), showing that the Tuscaloosa and Ellenton Formations at SRP are separated from the Congaree Formation by an effective confining layer. Figure F-10 shows the vertical head relationships near the southern boundary of the plant where the water elevation in the Tuscaloosa Formation is also higher than in the Congaree.

Figure F-10 also shows that the water elevation in the deep Tuscaloosa aquifer (Middendorf) is higher than that in the shallower Tuscaloosa aquifer (Black Creek) by at least 6 meters. This difference means that care must be exercised in constructing a Tuscaloosa piezometric map. Each aquifer must be mapped separately. Figure F-9 is a piezometric map of the Upper Tuscaloosa aquifer; the water elevations in P5A and P7A (both screened in the deep aquifer) are not shown (they are 7.6 meters and 3.0 meters higher than the shallower Tuscaloosa water elevations at those locations). | TC

Figure F-11 shows the vertical head relationships near M-Area where the Tuscaloosa water elevation is below that of the Congaree. At this location there is a continuous decline of head with depth indicating that this is a recharge area for the Tuscaloosa similar to much of the area of the Aiken Plateau northwest of Savannah River Plant.

In the outcrop area of the Tuscaloosa Formation, hydraulic gradients are steep (0.003) and ground-water velocities are correspondingly high. Downdip where the Tuscaloosa is overlain by a significant thickness of other coastal plain sediments, the gradients are gentler (0.0007) and the velocities are lower. Siple (1967) calculated the horizontal velocity of water of 52.2 meters per year using the hydraulic constants: hydraulic conductivity 4 x 10^4 liters per day per square meter (40.8 meters per day), a gradient of 0.0007, and an effective porosity of 20 percent. | TC | TC

Ground water is naturally discharged from the Tuscaloosa where the outcrop area is low in elevation, as in the Savannah River and Horse Creek valleys. In these regions, the base flow of streams is supported by discharge from the Tuscaloosa. As shown in Figure F-12, 22 years of pumping about 17 cubic meters per minute at the Savannah River Plant caused no progressive decline in water elevations in the prolific regional Tuscaloosa Formation. Tuscaloosa ground water use and development is discussed in Section F.3.

F.2.3.3 Water quality

Water from the Tuscaloosa Formation is low in dissolved solids (Table F-4). Specific analyses of water from the Tuscaloosa are given in Table F-5. Locations of the sampled wells are shown in Figure F-13. Because the water is soft and acidic, it has a tendency to corrode most metal surfaces (Siple, 1967). This is especially true where the water contains appreciable amounts of dissolved oxygen and carbon dioxide. The dissolved oxygen content of water from the Tuscaloosa Formation around the separations areas is very low (Marine, 1976b), and the sulfate content is about 13 milligrams per liter. The dissolved oxygen content is inversely related to the sulfate content of the water. In the northwest part of SRP nearer the outcrop area, water in the Tuscaloosa is near saturation with dissolved oxygen while the sulfate content is very low.

F.2.4 Ellenton Formation

F.2.4.1 Hydrostratigraphy

The Ellenton Formation overlies the Tuscaloosa Formation and consists of dark lignitic clay with coarse sand units. It is thought to be Late Cretaceous or Paleocene in age and is unconformably overlain by the Congaree Formation (of the Eocene Epoch). The known Ellenton sediments are entirely within the subsurface; they range in thickness from 0 near the northwest boundary of SRP to about 30 meters southwest of Savannah River Plant.

The Ellenton Formation was described and named by Siple from subsurface studies on the Savannah River Plant (Siple, 1967). The formation was not correlated outside of this area, but Siple speculated that it might be equivalent to the Black Creek Formation of Late Cretaceous age or the Black Mingo Formation of Paleocene or early Eocene age (Siple, 1967).

The lignitic clay is dark gray to black, sandy, and micaceous. It is interbedded with medium quartz sand, and contains pyrite and gypsum. The upper part of the formation is characterized by gray silty-to-sandy clay with which gypsum is associated. This clay is about 3 to 5 meters thick in the central part of SRP; it thickens to 10 meters in the A- and M-Areas, where laboratory measurements indicate that its vertical hydraulic conductivity is 9.8×10^{-5} meters per day. The lower part consists generally of medium-to-coarse clayey quartz sand, which is very coarse and gravelly in some areas (Siple, 1967). TC

In many places in the vicinity of SRP, there is a thick clay at the top of the Tuscaloosa (Figure F-5) which apparently separates the aquifers of the Ellenton and the Tuscaloosa. However, this clay contains lenses of sand that apparently connect the two aquifers. Although the Tuscaloosa Formation can be differentiated from the Ellenton Formation, the permeable or water-bearing zones within the two formations are not completely separated by an intervening confining bed (Siple, 1967). Since ground water is free to move from one formation into the other where the two formations are hydraulically connected, the permeable zones in the Tuscaloosa and Ellenton Formations are considered to constitute a single aquifer over a large part of the area including Savannah River Plant. The water levels shown in Figure F-5 indicate that this is the case.

F.2.4.2 Hydrologic characteristics

Some of the sand lenses in the Ellenton may be as permeable as sands in the Tuscaloosa, but they are not as thick as the Tuscaloosa sands, and are therefore not developed by wells as commonly as those of the Tuscaloosa. Pumping tests to determine hydraulic constants are rare in the Ellenton Formation. In general, Siple (1967) did not distinguish between the Ellenton and the Tuscaloosa formations in reporting the results of pumping tests. No piezometric map exclusively of the Ellenton Formation exists. Thus, little is known about the lateral flow path of water within the formation. Because it is apparently hydraulically connected to the Tuscaloosa Formation, its flow pattern is probably similar.

Figure F-5 shows the relationship at H-Area of the water elevation in the Ellenton to water elevation in the formations above and below. The water elevation in the Ellenton is above that in the Tuscaloosa in Figure F-5 because the Tuscaloosa wells are all within the cone of depression of the continuous pumping in H-Area. These Tuscaloosa observation wells are probably more responsive to the hydraulic effects of this local pumping than is the Ellenton well.

The hydraulic heads shown on Figure F-5 indicate that there is not a direct hydraulic connection between the Ellenton and the overlying Congaree Formation. Although the clays that separate the Ellenton and the Congaree are not thick, they are apparently extensive and continuous enough to impede the hydraulic connection. A pisolitic clay at the base of the Congaree appears to be extensive and may constitute the principal confining bed that separates that Congaree and the deeper hydrologic system (Siple, 1967). The upper part of the Ellenton is a sandy clay, which may also function as a confining bed between the Ellenton and the Congaree.

The poor hydraulic connection of the Ellenton with the Congaree and the apparent good connection with the Tuscaloosa can be explained on the basis of the sedimentary environments of these formations. The Tuscaloosa was deposited under nonmarine conditions, and therefore the sands and clays might be discontinuous. The Ellenton was deposited under both nonmarine and estuarine conditions. However, the Congaree was deposited under marine conditions, which would be conducive to deposition of extensive continuous layers of clay and layers of sand.

Because the Ellenton is entirely a subsurface formation, there is no natural discharge to the surface. Water passing through the Ellenton is principally recharged by and discharged to the Tuscaloosa Formation.

Although few wells pump exclusively from the Ellenton Formation, some wells that are screened in the Tuscaloosa are also screened in the Ellenton. Accordingly, the course of future well development in the Ellenton will parallel the development of the Tuscaloosa Formation. It is, however, difficult to estimate the quantity pumped from the Ellenton alone.

F.2.4.3 Water quality

A summary of chemical analyses of water from the Ellenton Formation is given in Table F-4. Its dissolved solids content is somewhat higher than that of water from the Tuscaloosa, but it is still very low at less than 50 milligrams per liter.

F.2.5 Congaree Formation

F.2.5.1 Hydrostratigraphy

The Congaree Formation was included in the McBean Formation by Cooke (1936), and this usage was followed by the U.S. Army Corps of Engineers (COE, 1952) during the original foundation studies for the construction of the Savannah River Plant (Marine and Root, 1978). The lower part of the original McBean was raised to formational status and called the Congaree Formation and the Warley Hill Marl by Cooke and McNeil (1952). In discussing geology and ground water at Savannah River Plant, Siple (1967) used the term "McBean" both to include all deposits of Claiborne age (see Table F-1) and to include only the upper part of these deposits. In much of the area studied by Siple, the two formations could not be distinguished, either where exposed or in well logs (Marine and Root, 1978).

Subsequent investigations at Savannah River Plant have shown that for hydrologic studies, it is desirable to distinguish the McBean Formation (as used in the restricted sense, rather than as used by Siple, 1967) from the Congaree Formation, because in the central part of Savannah River Plant the water elevation in the Congaree is about 24 meters lower than that in the McBean (restricted sense), and the Congaree is more permeable (Marine and Root, 1978). These two hydrostratigraphic units are separated by a clay layer informally called the "green clay" in studies at Savannah River Plant. This clay occupies the same stratigraphic position as the Warley Hill Marl of Cooke and McNeil (1952).

In discussing the geohydrology, the term McBean Formation will be used only in the restricted sense. The term "deposits of Claiborne age" will be used to refer to the broad sense in which the term "McBean Formation" was previously used (Cooke, 1936).

The deposits of Claiborne age strike about N 60°E and dip at a gradient of about 1.5×10^{-3} to 1.7×10^{-3} toward the south or southeast (Siple, 1967). Their thickness ranges from zero near the Fall Line to about 76 meters in southeastern Allendale County. In the central part of Savannah River Plant, the Claiborne deposits are about 61 meters thick (Figure F-5), of which about 37 meters is Congaree Formation.

In the central part of Savannah River Plant, the Congaree Formation consists of gray, green, and tan sand with some layers of gray, green, or tan clay (Marine and Root, 1978). In the northwest part of Savannah River Plant, it consists primarily of tan clayey sand. It is slightly glauconitic in some places, slightly calcareous in others. In some locations in Calhoun County, South Carolina, it consists of well to poorly sorted sand, fuller's earth, brittle siltstone, and light gray to green shale, alternating with thin-bedded fine-grained sandstone. Elsewhere in Lexington and Calhoun Counties, it includes tan, white, and reddish-brown cross-bedded sand very similar to that in the McBean Formation (Siple, 1967).

Although subdivision of the Claiborne group may be warranted in the SRP area and in other parts of South Carolina and Georgia, such subdivision appears less warranted toward the Fall Line because the shoreward facies of each unit grades into a comparatively thin zone, and criteria for distinguishing them become doubtful (Siple, 1967). That this is so is confirmed by drilling in the northwestern part of Savannah River Plant (M-Area), where the green clay is thin and discontinuous and the sediments of both McBean and Congaree are very similar in appearance.

A pisolitic clay zone at the base of the Claiborne deposits is the base of the Congaree Formation (Siple, 1967). If this characteristic clay is correlative with a similar pisolitic clay zone at the base of the Claiborne deposits on the Gulf Coast, then it is likely that the clay is continuous within the SRP area. This may be the effective confining bed that hydrologically separates the

TC aquifer in the Congaree Formation from that of the Ellenton Formation. In A- and M-Areas, laboratory tests indicate a vertical hydraulic conductivity of 1.8×10^{-4} meters per day.

The green clay layer at the top of the Congaree Formation appears to be continuous in the central SRP area. In the northwest SRP area (i.e., updip) it becomes discontinuous. This clay is hydrologically significant because it supports a large head differential between water in the McBean Formation above and water in the Congaree Formation below. In the northwest SRP area where the clay is discontinuous, the head differential is not as large. To the south it ap-
TC pears that the green clay thickens to about 7 meters in L-Area and 18 meters in the southeastern portions of the SRP to become what is referred to in Georgia as the Blue Bluff Marl of the Lisbon Formation (Figure F-4). It is encountered at the Vogtle Nuclear Power Station in Georgia, in wells in the southern part of the Savannah River Plant, and offsite to the south. However, intermediate wells that confirm the tentative correlation of the green clay with the Blue Bluff Marl do not exist. The green clay is herein considered to be part of the Congaree Formation even though there is no faunal support for this assignment. This clay consists of gray-to-green, dense, occasionally indurated clay (Marine and Root, 1978). The indurated nature of the clay is commonly caused by dense compaction and siliceous cement. Calcareous cement is usually absent from this indurated zone. Farther south calcareous cement may be more common.

The sand beds of the Congaree Formation constitute an aquifer in this region that is second only to the Tuscaloosa aquifer in productivity. Maximum yields of 2.5 cubic meters per minute with 15 meters of drawdown have been reported from wells in Claiborne deposits on SRP (Siple, 1967). Much of the water produced by high-yielding wells reported to be pumping from the McBean Formation (Siple, 1967) in the broad sense, i.e., Claiborne deposits, probably comes from the Congaree Formation. Another well in these deposits yielded only 0.66 cubic meters per minute with 15 meters of drawdown. Wells in the municipal well field at Barnwell, South Carolina, have yielded as much as 1.5 cubic meters per second with 12 meters of drawdown. However, in other areas such as northwestern SRP (M-Area), the yield may be as low as 0.11 cubic meters per minute with 9 meters of drawdown.

F.2.5.2 Hydrologic characteristics

Table F-6 lists hydraulic constants for the Claiborne deposits. Two of the tests, which were located near the central part of SRP, indicated a hydraulic conductivity of nearly 40,000 liters per day per square meter, whereas one of the values (730 liters per day per square meter) in M-Area is 50 times less than this. The median conductivity value for 10 slug tests (decay of an instantaneous head change) in sandy zones of the Congaree Formation in the separations areas of Savannah River Plant was 1800 liters per day per square meter (Root, 1977a, 1977b). The median conductivity of two water-level recovery tests was 1500 liters per day per square meter. Values for the median hydraulic conductivities for the Tertiary hydrostratigraphic units (Table F-1) in the separations areas determined from aquifer tests are shown in Table F-7. The results of pumping tests, recovery tests, and slug tests on Tertiary units in the separations areas are shown in Figure F-14.

Table F-7. Median hydraulic conductivities of Tertiary hydrostratigraphic units as determined by pumping tests

Formation	Conductivity[a] (m/day)
Barnwell sand lens	0.3
Barnwell clayey sand	0.04
Barnwell silty sand	---
Upper McBean	0.13
Lower McBean	0.07
Congaree	1.5

[a]Adapted from Marine and Root (1976).

Laboratory tests by the U.S. Army Corps of Engineers (COE, 1952) indicated a median value of 43 percent for the total porosity of the upper part of the Congaree Formation. A reasonable effective porosity (used in calculating ground-water velocity) is estimated as 20 percent. A pumping test in northwest Savannah River Plant gave a value of 14 percent.

Figure F-5 shows the water elevation in the Congaree Formation and its relationship to that in the hydrostratigraphic units above and below. These data are for one location in the separations areas where water-level differences are probably at their maximum. Near the discharge areas of creek valleys, water elevations of the several Tertiary aquifers converge (Figure F-15).

The natural discharge areas for the Congaree Formation at Savannah River Plant are the swamps and marshes along Upper Three Runs Creek and along the Savannah River Valley. Although springs do occur, most of the discharge occurs along the valley bottoms in swamps, making it difficult to measure flow rates of the discharge.

On a regional basis, the dissecting creeks divide ground water in the Congaree Formation into discrete subunits. Thus, even though the hydraulic characteristics of the formation may be similar throughout the area, each subunit has its own recharge area and its own discharge area. If dissection is through most of the formation thickness, then no water moves from one subunit to another.

The fluctuation of water elevations in the Congaree Formation and their relationship to those in other hydrostratigraphic units is shown in Figure F-16. The spatial variation of water elevations in the Congaree Formation in the separations areas is shown in Figure F-17. This piezometric map indicates a northwestward movement of water across the separations areas. This direction of movement is governed by the discharge of the water in the Congaree Formation to Upper Three Runs Creek, where the green clay, is breached. Because Four Mile Creek does not breach the green clay, the piezometric map is unaffected by its valley.

As shown in Figure F-18 the water elevations in the Congaree Formation are significantly drawn down by the ground-water discharge to the Savannah River and to Upper Three Runs Creek. Two regional piezometric maps of the Congaree have been recently published (Faye and Prowell, 1982; Georgia Power Company, 1982), but neither reflects the significant drawdown due to the incision of the formation by Upper Three Runs Creek.

The vertical head relationships of the Congaree to the units above and below are shown in Figures F-5, F-15, and F-16. These figures show that the head in the Congaree Formation in the separations areas is the lowest of any hydrostratigraphic unit in the coastal plain system. This is brought about by two factors: (1) the low permeability of the green clay through which recharge must take place, and (2) the high hydraulic conductivity of the Congaree sands below the green clay, which enhances lateral movement and discharge to the deeper creek valleys. Upward recharge of water to the Congaree from the Ellenton-Tuscaloosa systems is also impeded by clay layers at the base of the Congaree and at the top of the Ellenton.

The lateral hydraulic gradient, I, in the Congaree Formation (Figure F-18) ranges from about 0.003 to 0.005. Using a hydraulic conductivity, K, of 1.5 meters per day (Table F-7) and an effective porosity, j, of 20 percent, the flow velocity (Darcy's Law) is

$$V = \frac{IK}{j} = \frac{365 \text{ days/yr} \times 0.005 \times 1.5 \text{ m/day}}{0.20} = 13.7 \text{ m/yr}$$

In the A- and M-Areas, the lateral flow velocity is about 3.2 to 7.6 meters per year; in the southern part of the Plant, the velocity is calculated to be 160 meters per year. TC

The Congaree Formation provides water to Savannah River Plant (tens to hundreds of liters per minute) and to the rural population around Savannah River Plant. In the M-Area vicinity the Congaree Formation is clayey sand rather than sand as it is farther downdip. Thus well yields in this area are not nearly as high as in the downdip areas. For example, a hydraulic conductivity value of 730 liters per day per square meter in M-Area (Table F-6) is only 2 percent of the value of 40,000 liters per day per square meter obtained from pumping tests near C-Area and P-Area. In the future, pumpage will increase from both the Congaree and Tuscaloosa Formations, but increases are expected to occur more rapidly in the Tuscaloosa.

F.2.5.3 Water quality

Summary of chemical analyses of water from deposits of Eocene age (McBean and Congaree Formations) is given in Table F-4 as reported by Siple (1967). These analyses are grouped into those from Eocene limestone, which would be primarily for water from the McBean Formation but might include some analyses of water from the Congaree Formation, and those of water from Eocene sand, which would include the Barnwell, McBean, and Congaree Formations.

The analyses of water from the Eocene sands are similar to those from the Tuscaloosa Formation, which is also predominantly sand. The water is low in dissolved solids (about 20 milligrams per liter) and is acidic (pH about 5.5). In comparison, the water from the Eocene limestone is much higher in dissolved solids (about 100 milligrams per liter) and is nearly neutral (pH about 7). Most of the increase in dissolved solids is due to increases in calcium and bicarbonate ions, as would be expected from sediments high in calcium carbonate.

Two analyses of water from sands in the Congaree Formation are shown in Table F-5. The analyses are similar to those reported for Eocene limestone by Siple (1967), including a high calcium and bicarbonate content. These zones in the Congaree Formation probably contained some calcareous cement, giving rise to the ionic content of this water.

F.2.6 McBean Formation

F.2.6.1 Hydrostratigraphy

As previously discussed, the term McBean was originally used to designate all deposits of Claiborne age in this area, but it is now used to designate only the upper part of these sediments. Even though this distinction was originally made on a stratigraphic basis, the distinction is even more significant on a hydrologic basis. Hydraulic head differences between the McBean and Congaree Formations are large in many places, and the Congaree is about 10 times more permeable than the McBean.

The McBean Formation may be divided into two subunits, an upper unit consisting of tan clayey sands and occasionally red sand (Marine and Root, 1978), and a lower unit consisting of light tan-to-white calcareous clayey sand. This lower unit is locally referred to as the "calcareous zone"; in some places, it contains void spaces that could result in rod drops or lost circulation during drilling operations (COE, 1952). To the northwest these void spaces appear to decrease so that no calcareous zone exists in the northwest part of Savannah River Plant (M-Area). However, to the southeast the lime content of the zone increases as do void spaces. Southeast of Savannah River Plant the zone becomes a limestone with only small amounts of sand; and its water yielding potential increases.

The McBean Formation is considered to be the shoreward facies of the Santee limestone, which occurs to the southeast (Siple, 1967). In the SRP area, the "calcareous zone" may represent a tongue of the Santee limestone. Toward the Fall Line to the northwest of SRP, it becomes more difficult to distinguish the several Eocene formations, and Siple (1967), maps the Eocene deposits undifferentiated. In the northwest SRP area (M-Area), the calcareous zone is replaced by a clayey sand unit.

Ground water occurs in both the upper sandy unit and in the calcareous zone, but neither are prolific aquifers in the central part of SRP. Farther to the southeast, where the calcareous content as well as the number and size of the voids in the calcareous zone increase, well yields are moderate.

As with the Congaree Formation, creeks in the region dissect the McBean Formation, and divide the hydrogeologic unit into separated subunits, each having its own recharge and discharge area. Because the McBean is a shallower formation than the Congaree, smaller creeks with less deeply incised valleys make these divisions. The subunits of the McBean are therefore smaller than those of the Congaree. In the separations areas, the only stream that cuts into the Congaree is Upper Three Runs Creek, whereas the McBean is incised by Upper Three Runs Creek, several of its larger tributaries, and Four Mile Creek. Thus, ground water that enters the McBean Formation in the separations areas cannot migrate to other subunits of the McBean.

F.2.6.2 Hydrologic characteristics

The median hydraulic conductivity of the upper sand of the McBean Formation is 130 liters per day per square meter (0.13 meters per day) and that of the calcareous zone is about half that of the upper sand (Table F-7). Figure F-14 shows the median and range of hydraulic conductivity as measured in the field by slug tests, recovery tests, and drawdown tests. Figure F-19 shows the range and median of laboratory measurements of hydraulic conductivity. An effective porosity of 20 percent is presumed reasonable.

Fluid losses in the calcareous zone during drilling operations make it appear very permeable. However, pumping tests on the calcareous zone indicate a low hydraulic conductivity (Table F-7, Figure F-14). Apparently zones of higher permeability do not connect over large distances, and the regional permeability of the calcareous zone is lower than it appears from drilling experience.

Water elevations in both the upper sand unit and in the calcareous zone are shown in Figures F-5 and F-16. These data, based on wells in the recharge area, indicate a difference of about 0.6 meter in hydraulic head between the top of the McBean and its base. This indicates a better hydraulic connection between the sandy unit of the McBean and the calcareous zone than between the McBean and the Congaree Formations below or the Barnwell Formation above.

Figure F-20 shows the piezometric surface of the upper part of the McBean Formation in the separations areas. This map indicates lateral flow in the upper part of the McBean Formation toward Upper Three Runs Creek to the north and toward Four Mile Creek to the south. Because of the hydraulic connection between the upper sandy zone and the calcareous zone, Figure F-20 can also be used to determine the approximate flow path of water in the calcareous zone.

As previously described, the green clay impedes downward movement of water from the McBean to the Congaree Formation in the central part of Savannah River Plant, thereby contributing to a hydraulic head differential of about 24 meters (Figure F-5). In the Barnwell Formation just above the McBean Formation, a tan clay impedes vertical movement of water from the Barnwell Formation into the McBean. This tan clay is not as continuous as the green clay, and it has a higher hydraulic conductivity. The McBean Formation is less permeable than the Congaree; thus, the head differential between the Barnwell and the McBean Formation is only about 4 meters (Figure F-5).

Using the previously given hydraulic conductivity, and effective porosity along with an appropriate hydraulic gradient of 0.017, the average horizontal velocity of the McBean in the central part of Savannah River Plant is calculated (by Darcy's Law, as was done for the Congaree) as 4.0 meters per year. Assuming the same gradient as for the Upper McBean, the regional ground-water velocity in the calcareous zone is 2.2 meters per year.

In the northwest part of Savannah River Plant (M-Area) the average hydraulic conductivity of the McBean and Congaree Formations together, as determined from a pumping test, is 0.75 meter per day and the average velocity is about 6.1 meters per year. The main body of the chlorinated hydrocarbon plume in the A- and M-Areas is moving at a rate of 7.6 meters per year; the outer fringe is moving at 76 meters per year. TC

Water from the McBean Formation is not used for industrial or municipal purposes. Larger wells producing from the Claiborne deposits probably derive most of their water from the Congaree. The McBean is, however, sufficiently permeable in some places to supply water for domestic use.

Because the McBean Formation is not used for large supplies of water, it is not anticipated that there will be much future change from water use in the hydrologic regimen of this formation. The head differential between the McBean and Congaree is about 24 meters at present, and even if the Congaree were subjected to additional drawdown, it is unlikely that there would be much effect on the McBean hydrology. Dissection of the McBean by local creeks also divides the formation into subunits whose hydrologic regimen is unaffected by adjacent subunits. Thus, increased development in one of the subunits would have little effect on the regional hydrology of this formation.

F.2.6.3 Water quality

Samples of water from Eocene sand and Eocene limestone probably include some water from both the upper sand and the calcareous subunits of the McBean Formation. The median and range of chemical analyses are listed in Table F-4. The water from both subunits is low in dissolved solids, but water from the upper sand subunit is much lower. The differences in the chemical characteristics of water from the two subunits of the McBean are readily apparent in Table F-5. Well HC3D in the upper sandy unit has a total dissolved solids content of 14 milligrams per liter with all constituents being very low. The other two wells are screened in the calcareous zone and have a dissolved solids content of more than 50 milligrams per liter with higher calcium and bicarbonate contents. The pH of the water from the calcareous zone is near 7, while that of water from the upper sandy zone is generally less than 5.

F.2.7 Barnwell Formation

F.2.7.1 Hydrostratigraphy

The Barnwell Formation directly overlies the McBean Formation and is exposed over a considerable area in the uplands of Aiken and Barnwell Counties. The formation thickens to the southeast from zero in the northeastern part of Aiken County to about 27 meters at the southeast boundary of Barnwell County. The Barnwell Formation is overlain by the Hawthorn Formation, from which it is usually difficult to distinguish from the Barnwell. In the separations areas, these two units together are usually about 30 meters thick (Figure F-5).

The Barnwell Formation consists mainly of deep red fine-to-coarse clayey sand and compact sandy clay. Other parts of the formation contain beds of mottled-gray or greenish-gray sandy clay and layers of ferruginous sandstone that range in thickness from 0.03 to 1 meter. Although fossils at some places indicate a marine origin, material identified as Barnwell may have been deposited in other places as alluvium during Pliocene to Pleistocene time (Siple, 1967). Beds of limestone occur in the Barnwell Formation in Georgia, but none have been recognized in South Carolina.

These factors indicate that a considerable part of the Barnwell Formation was deposited as a sandy limestone in a near-shore or estuarine environment. Some evidence of the remnant calcareous nature of the formation is indicated by the comparatively high proportion of calcium carbonate found in ground water circulating in this unit (Siple, 1967).

In the separation areas, the Barnwell Formation appears divisible into three parts:

1. The lowest unit, the tan clay, commonly consists of two thin clay layers separated by a sandy zone. The entire unit is about 3 to 4.5 meters thick and is semicontinuous over the area.

2. Above the tan clay is a silty sand unit, 0 to 12 meters thick.

3. Above the silty sand is a unit of clayey sand (that may include beds of silty clay or lenses of silty sand) to 30 meters thick. This sand is slightly less permeable than the underlying silty sand.

Because of the large amount of clay and silt mixed with the sands, the Barnwell Formation does not generally yield water to wells. However, an occasional lens of sand may be relatively free of clay and can provide adequate quantities of water for domestic use.

F.2.7.2 Hydrologic characteristics

Laboratory measurements of hydraulic conductivities of many undisturbed Barnwell samples, as well as results of point-dilution tracer tests, are shown in Figure F-19. The median conductivity was 0.04 meter per day for the clayey sand unit (Table F-7 and Figure F-15). Although no pumping tests were made on the silty sand unit, a pumping test in a sand lens within this unit indicated a hydraulic conductivity of 0.3 meter per day (Table F-7).

The relationship of water elevations in different zones within the Barnwell, as well as the relationship of these levels to those in the formations below, are shown in Figures F-5 and F-15. The variations of water levels in the Barnwell over a period of five years are shown in Figure F-16. This figure indicates that the amplitude of water elevation fluctuation is greater in the Barnwell than in the formations below.

Figures F-5 and F-15 show a hydraulic head that decreases with depth within the Barnwell Formation. Although the tan clay impedes the downward movement of water, the McBean Formation is recharged by water that passes through this hydrostratigraphic unit.

The water table is commonly within the Barnwell Formation, although in the creek valleys it successively occupies positions in the lower formations (Figure F-15). A map of the elevation of the water table is shown in Figure F-21. The surface drainage and topography strongly influence the flow path at any point. Even small tributaries to the larger creeks cause depressions in the water table, diverting ground-water flow towards them.

Using an overall average gradient for the water table of 0.018, a hydraulic conductivity for the clayey sand unit of 0.04 meter per day (Table F-7), and an effective porosity of 20 percent, the ground-water velocity through Barnwell material is calculated as 1.3 meters per year. If a sand lens with a hydraulic conductivity of 0.3 meter per day (Table F-7) existed for the entire flow path, the velocity would be 9.7 meters per year. A series of tracer dilution tests and tracer injection detection tests yielded velocities ranging from 0.7 to 21 meters per year (Fenimore, 1968).

Natural discharge from the water table, which is predominantly in the Barnwell Formation, is to the creeks and their tributaries on Savannah River Plant. The areas of perennial creek drainage are shown by the solid lines representing creeks in Figure F-21.

The Barnwell Formation supplies water for domestic purposes in some places in the region, but it is not used by industry or municipalities. Total pumpage has not been estimated, but is small. The future ground-water levels of the Barnwell Formation will mainly depend on natural conditions such as rainfall.

F.2.7.3 Water quality

Five analyses of water from the Barnwell Formation in the separations areas are given in Table F-5. The dissolved solids content is low, and the calcium and bicarbonate ions are not as high as in the McBean and Congaree Formations. The pH of water from the Barnwell Formation is as low as that of water from other formations in the area.

F.2.8 Hawthorn Formation

F.2.8.1 Hydrostratigraphy

The Hawthorn Formation crops out over a very large area of the Atlantic Coastal Plain and is perhaps the most extensive surficial deposit of Tertiary age in this region (Siple, 1967). It is bounded on top and bottom by erosional unconformities, and is present at the surface in the higher areas of Aiken County. It ranges in thickness from zero in northwestern Aiken County to about 25 meters near the Barnwell-Allendale County Line.

Typical Hawthorn Formation is fine, sandy, phosphatic marl or soft limestone and brittle shale resembling silicified Fuller's earth. Updip, however, in the vicinity of Aiken and Barnwell Counties, it is characterized by tan, reddish-purple, and gray sandy, dense clay that contains coarse gravel, limonitic nodules, and disseminated flecks of kaolinitic material.

The fine-grain materials within the Hawthorn Formation, consisting of compact silt and clay, are incapable of yielding water and are therefore not suitable for wells (Siple, 1967). The Hawthorn Formation is above the water table throughout much of the SRP area. However, where low permeability beds are overlain by more permeable beds, perched water bodies may occur.

F.2.8.2 Hydrologic characteristics

Because the Hawthorn Formation in the SRP area is usually unsaturated, no pumping tests have been performed. There is no piezometric map of the Hawthorn Formation in this area. Flow paths are predominantly vertical, with only short horizontal flow paths.

Within the Hawthorn there are numerous clastic dikes that criss-cross the clayey sand of the formation. These dikes are generally filled with greenish-gray silty-to-sandy clay (Du Pont, 1980). The dike wall, 0.5 to 2.5 centimeters thick, is generally indurated and consists of an iron oxide-cemented quartz sand (Siple, 1967). Thus, the dike filling is generally finer grained than the surrounding sediments. The origin of the dikes is uncertain. Possible explanations include (1) shrinkage resulting from weathering, (2) seismic activity, and (3) relief of compressional stresses by upward movement of plastic material (Siple, 1967).

F.2.8.3 Water quality

No water samples from the unsaturated zone have been analyzed.

F.2.9 Surficial formations

F.2.9.1 Tertiary alluvium

Alluvial deposits of Late Tertiary age occur irregularly and discontinuously on the interstream divides or plateaus. They are composed of coarse gravel and poorly sorted sand and were tentatively classified by Siple (1967) as Pliocene in age. Their thickness ranges from 1.5 to 6 meters. These deposits are generally considerably above the water table and are therefore unimportant as a source of ground water for wells. Nevertheless, they are fairly permeable, and are capable of storing and transmitting water. Their presence therefore enhances recharge to underlying formations.

F.2.9.2 Terrace deposits

Cooke (1936) recognized seven marine terraces of Pleistocene age on the Atlantic Coastal Plain of South Carolina. He indicated that the four highest terraces are present in the Savannah River Valley. The deposits that may be associated with these terraces are on the order of 10 meters thick or less (Cooke, 1936). Because of their near-surface location, they are not important as sources of well water.

F.2.9.3 Holocene alluvium

Alluvium of Holocene age occurs in the tributary and main channels of the Savannah River. These deposits, which are generally cross-bedded and heterogeneous in composition, range in thickness from 1.5 to 9 meters (Siple, 1967). The poorly sorted sand, clay, and gravel have little potential for ground-water development except along the larger streams where infiltration galleries might be possible.

F.2.10 <u>Hydrostratigraphy at L-Area</u>

The hydrostratigraphy at L-Area can be developed from the regional hydrostratigraphy as well as geological investigations and well logs at L-Area. Figure F-22 shows a hydrostratigraphic section from Pen Branch to Steel Creek developed from foundation borings (COE, 1952) and the driller's log from one of the water wells (29-L). Figure F-23 shows two cross sections through L-Area down to an elevation of about 12 meters above sea level. The tan clay is not TC readily evident from foundation borings, drillers logs, or geophysical well logs; however, even in other areas of the Savannah River Plant where it supports a significant head difference, this clay is not always apparent in soil cores alone. The calcareous zone is quite evident as it should be in this downdip location where the original lime content of the zone was greater. The green clay is recognizable in the water well driller's log, but cores might indicate that it is thicker than shown in the driller's log. Based on self-potential, TC resistivity, and gamma-ray geophysical well logs of wells 104L and 55-2, the green clay is 7 meters thick. (Figure F-24 shows the areas of the well field.) The Congaree Formation is not distinctive on the driller's log, but the upper aquifer of the Tuscaloosa Formation is noted in logs.

Figure F-24 is a water table map in the vicinity of L-Area. The water table in this area is unaffected by plant pumpage and is subject only to variation in local precipitation. The water table is between 3 and 6 meters below the surface (60 to 75 meters above sea level). The water table has a gradient EN-44 of approximately 0.0188 (including the head of water in the seepage basin), resulting in lateral flow from the seepage basin toward Steel Creek. If the hydraulic conductivity of the Barnwell (water table) Formation at L-Area was EN-44 0.6 meter per day (Section F.2.6.2), the lateral ground-water velocity would be about 21 meters per year. Root (1983) suggests that a lateral ground-water velocity of 14.5 meters per year per percent gradient is appropriate for the

EN-44 Barnwell Formation. This relationship yields a lateral velocity of about 27 meters per year between the L-Reactor seepage basin and Steel Creek. Because the L-Reactor seepage basin will not receive continuous discharges of low pH wastewater that enhance seepage (as in F- and H-Areas), a travel time of at least 18 years is expected for the 600-meter path between the basin and the creek.

Water levels have not been measured in the McBean or Congaree Formations at L-Area, but Figure F-18 indicates that the water level in the Congaree Formation should be about 50 meters above sea level. The water elevation in the Tuscaloosa Formation (Well 29-L) was 57 meters in 1951 before pumpage began. In 1982 the static Tuscaloosa water level was 55 meters in elevation. Thus, the heads decrease with depth to the Congaree Formation and then increase with depth in the Ellenton and Tuscaloosa Formations.

F.3 GROUND-WATER DEVELOPMENT

F.3.1 Use of ground water

Ground-water users within a 32-kilometers radius of the center of SRP were surveyed. Information was obtained from the South Carolina Department of Health and Environmental Control (SCDHEC), the South Carolina Water Resources Commission (South Carolina Water Resources Commission, 1971; Dukes, 1977), from files at the Savannah River Plant, and from Siple (1967).

Most municipal and industrial water supplies in Aiken County are developed from the Tuscaloosa Formation, which occurs at shallower depths as the Fall Line is approached. Domestic water supplies are primarily developed from the Barnwell, McBean, and Congaree Formations. In Barnwell and Allendale Counties, the Tuscaloosa Formation occurs at increasingly greater depths; some municipal users are therefore supplied from the shallower Congaree and McBean Formations or from their limestone equivalent. In these counties, domestic supplies are developed from the Barnwell and the McBean Formations.

The survey identified 44 municipalities and industries that use more than 18.9 cubic meters per day from ground-water sources. The total pumpage for these users is about 106,300 cubic meters per day. The locations of these users TC are shown in Figures F-25 and F-26, together with ground-water flow paths for the Tuscaloosa and Congaree Formations, respectively. Pertinent data are listed in Tables F-8 and F-9.

F.3.1.1 Municipal use

TC Twenty municipal users, with a combined withdrawal rate of about 39,000 cubic meters per day, were identified (Table F-8). Talatha community (in Aiken County), the municipal user nearest to the center of the Savannah River Plant (about 11 kilometers away), uses about 150 cubic meters per day. The largest municipal user is the town of Barnwell (in Barnwell County), about 26 kilometers away; it uses 15,140 cubic meters per day, some of which is supplied to local industry.

Total municipal pumpage from the Tuscaloosa Formation is about 23,500 cubic meters per day. Total municipal pumpage is 38 cubic meters per day from the McBean Formation and 15,000 cubic meters per day from the Congaree Formation. TC

F.3.1.2 Industrial use

Twenty-four industrial users were identified as shown in Table F-9, including 13 SRP users. Total industrial pumpage from the Tuscaloosa Formation, including the Savannah River Plant, is about 67,300 cubic meters per day. TC

The Barnwell Nuclear Fuel Plant has not, nor is it currently expected to operate and the only pumpage (for domestic purposes, boiler make-up, and wash water) is estimated to be about 0.76 cubic meter per minute from one Tuscaloosa well and one Congaree well. The Sandoz Plant, about 29 kilometers south of the center of Savannah River Plant, is the largest offsite industrial user and pumps about 10,900 cubic meters per day from one Tuscaloosa well. This pumpage began about 1978.

Construction work at the Vogtle Nuclear Power Plant, across the Savannah River from Savannah River Plant restarted in 1977. Water is supplied from two Tuscaloosa wells about 260 meters deep and three shallower wells about 73 meters deep, probably in the Congaree Formation. The average pumping rate for the total five-well system was 950 cubic meters per day in 1982. This pumpage also began about 1978.

F.3.1.3 Agricultural use

In 1980 irrigation from ground-water sources in Allendale County amounted to an average annual pumping rate of 15,000 cubic meters per day. In Barnwell County this amounted to 4100 cubic meters per day. Most of the growth of irrigation systems in these two counties has taken place over the last several years. Some of these irrigation systems are in the Tuscaloosa, but some are in the limestone equivalent of the McBean or Congaree Formations.

F.3.1.4 Domestic use

In addition to the large municipal and industrial users, 25 small communities and mobile home parks, 4 schools, and 11 small commercial interests are listed in the files of the South Carolina Department of Health and Environmental Control as using ground water. Wells serving these users are generally equipped with pumps of 54 to 325 cubic meters per day capacity and do not draw large quantities of water. Most produce from shallow aquifers. The estimated total withdrawal from these 40 users is about 1000 cubic meters per day. However, incomplete State records provide little information on screened zone, formation, or actual usage. Two South Carolina State Parks are within the survey area: (1) Aiken State Park, with seven wells, and (2) Barnwell State Park, with two wells. The Edisto Experimental Station at Blackville pumps an average of 70 cubic meters per day from the Congaree Formation. Several shallow wells produce small quantities (pump capacity of less than 40 liters per minute) of water for guardhouses at the Savannah River Plant.

There are a large number of shallow drilled and dug wells in the survey area outside of Savannah River Plant. Pumpage from these wells is not included in this survey.

F.3.2 SRP ground-water usage

Table F-10 shows the pumping rates from 1968 to 1983 for individual areas at SRP. The location of most of these areas is shown in Figure F-25. The centers for greatest ground-water pumpage at Savannah River Plant are in A-, F-, and H-Area. The total pumpage at Savannah River Plant is shown in graphical form in Figure F-27. In 1983 annual ground-water usage was 27.0 cubic meters per minute. Siple (1967) concluded that (1) the Tuscaloosa aquifer can supply about 37.8 cubic meters per minute for the operation of Savannah River Plant with no adverse effects on pumping capabilities in existing 1960 wells; and (2) potentially, the aquifer could produce more water if well fields were properly designed. In 1960 the SRP pumpage from the Tuscaloosa was about 18.9 cubic meters per minute.

F.4 HYDROLOGIC INTERRELATIONSHIPS AT SRP

F.4.1 Natural interrelationships

Although a number of hydrologic interrelationships between the various hydrogeologic units at Savannah River Plant have been discussed in Section F.2, which describes the hydrostratigraphic units, the purpose of this section is to summarize and amplify these relationships.

Precipitation at Savannah River Plant averages about 121 centimeters per year with a maximum of 187 centimeters in 1964 and a minimum of 73 centimeters in 1954 (for the period 1952 through 1982). Table F-11 shows the monthly precipitation at Savannah River Plant near the administration area since 1952. Although there may be both spatial and temporal variations in the fraction of this precipitation that recharges the ground water, the overall average annual recharge is about 30 percent of the total or 38 centimeters. This value varies with slight variations in the hydraulic conductivity of the shallow layers of sediment, the proportion of the rainfall that falls in the nongrowing season, the antecedent wet or dry conditions, and drainage patterns.

Infiltrating water moves vertically through the unsaturated zone at a rate of about 2 meters per year in the central part of Savannah River Plant to recharge the water table which is commonly in the Barnwell Formation. This rate varies spatially and temporally. Upon reaching the water table, the recharging water travels on a path that has both vertical and horizontal components. The magnitude of these two components depends on the vertical and horizontal components of the hydraulic conductivity. Clay layers of low hydraulic conductivity tend to impede vertical flow and enhance horizontal flow. If the horizontal hydraulic conductivity is low, recharging water will tend to "pile up" above the clay, and the water table will be high, or perched. On the other hand, if the hydraulic conductivity is high, the recharging water will be conducted more quickly away from the recharge area, and the water table will be low.

Figure F-5 shows the head relationship of the various hydrostratigraphic units in the central part of Savannah River Plant (which includes F-, H-, and L-Area), and Figure F-15 shows how these relationships change as Upper Three Runs Creek is approached. The water table is high in this area because the tan clay inhibits the downward movement of water and the low horizontal hydraulic conductivity of the Barnwell Formation does not permit rapid removal of the water in a horizontal direction. The head builds in the Barnwell Formation sufficiently to drive the water through the material of low hydraulic conductivity--some going vertically through the tan clay and some moving laterally to the nearby tributary streams. Although there are temporal variations in the elevation of the water table, there is an overall equilibrium of the water table that depends on hydraulic conductivity, the geometry of the system, and its discharge points.

Water that enters the McBean Formation also moves on a path that has both vertical and horizontal components. The water recharging this formation through the tan clay is the difference between 38 centimeters per year and the amount of water that is removed from the Barnwell by lateral flow. Also, compared to the Barnwell Formation, the discharge points for the deeper McBean Formation are more distant from their respective ground-water divides.

The green clay has a lower hydraulic conductivity than the tan clay. As a result, recharge to the Congaree through this clay is less than the recharge to the McBean. Most of the recharge is from offsite areas. In addition, the Congaree has a higher hydraulic conductivity than the material above and as a result lateral flow is enhanced making the water levels in the Congaree much lower than those above (Figures F-5 and F-15). The discharge areas for the Congaree are the valleys of the Savannah River and Upper Three Runs Creek. Even though these discharge areas are more distant from the central part of Savannah River Plant than the discharge areas for the Barnwell and McBean Formations, the hydraulic conductivity is sufficiently high so that the natural discharge from the Congaree makes its water level much lower in this area than the formations above.

Tuscaloosa Formation water elevations in the central part of Savannah River Plant are above those in the Congaree (Figure F-5) showing that in this area, the Tuscaloosa is not naturally recharged from the Congaree. However, this upward head differential has been decreasing at about 0.16 meter per year over the AW-1

AW-1 past 10 years, primarily because of increased SRP pumping (Section F.4.2). Water in the Tuscaloosa passing beneath this area is recharged through the Tertiary sediments to the north of Savannah River Plant (Figure F-7). Water is discharged from the Tuscaloosa upward into the overlying sediments in the Savannah River Valley. This relationship is shown on Figure F-28 which is a hydrologic section through H-Area approximately perpendicular to the Savannah River. This diagram shows that in the Savannah River Valley and Upper Three Runs Valley, the head in the Tuscaloosa is consistently above that of the Congaree. Water levels in the Tuscaloosa in the Savannah River Valley are commonly above land surface and wells in these areas flow naturally. This figure also shows that water from either the Tuscaloosa or the Congaree does not naturally flow from South Carolina to Georgia or vice versa. Piezometric maps prepared in 1982 confirm these facts (Georgia Power Company, 1982).

Figure F-10 shows the vertical head relationships between the Congaree, shallow Tuscaloosa, and deep Tuscaloosa in the southern part of Savannah River Plant. The head relationship between the Congaree water level and higher Tuscaloosa water elevation is the same here as in H-Area but the head difference is greater. This area is greatly influenced by the drawing down of the head in the Congaree due to the nearness of the Savannah River Valley.

The head relationships in the northwest part of Savannah River Plant (M-Area) are quite different as shown on Figure F-11. In this updip area, the green clay is discontinuous and is thinner than it is farther downdip. The tan clay has disappeared entirely. Thus, there is little impedance to downward vertical flow within the Tertiary sediments and the water levels are deeper below land surface. The sands of the Congaree Formation are not as well sorted and the hydraulic conductivity in the Congaree near M-Area is lower than that in the central part of Savannah River Plant. As a result, the lateral flow of water in the Congaree is insufficient to draw its water elevation down below that of the Tuscaloosa, thereby creating a downward head differential from the Congaree to the Tuscaloosa. Closer to the Savannah River, the discharge from the Congaree draws its water level down below that of the Tuscaloosa (Figure F-29).

The Congaree and Tuscaloosa Formations are separated in M-Area even though this area is near the updip termination of the Ellenton Formation. In places, the Ellenton consists of 18 meters of sandy clay of low hydraulic conductivity, but it appears not to be this thick continuously. Thus there may be discontinuous recharge from the Congaree to the Tuscaloosa through the Ellenton in this area.

An indication of the location of areas where there is a head reversal between the Congaree and the Tuscaloosa (higher head in the Tuscaloosa), and areas where there is not, may be obtained by constructing a map showing the difference between the Tuscaloosa piezometric map (Figure F-9) and the Congaree piezometric map (Figure F-18). This head difference map (Figure F-30) shows that the head in the Tuscaloosa is higher than the head in the Congaree in a broad area within about 10 kilometers of the Savannah River and Upper Three Runs Creek. The head in the Congaree is higher in an area around M-Area, as discussed previously, and in the vicinity of Par Pond. It must be emphasized that this map is constructed by subtracting two piezometric maps for which data are somewhat sparse. Thus it should not be used to predict detailed head relationships but only to indicate general areas of expected relationships.

F.4.2 Relationship of ground-water use to water levels

In 1974 Marine and Routt (1975) made a numerical model study of the Tuscaloosa Formation in the vicinity of Savannah River Plant to assess the impact of additional planned water withdrawals from the Tuscaloosa Formation on water elevations at the Plant. The model focused on the water flux through the Tuscaloosa beneath the Plant and excluded water in the outcrop area that is recharged and discharged to the Tuscaloosa in very short distances (Figure F-31). Marine and Routt calculated a flux of 110 cubic meters per minute as being representative of conditions in the Tuscaloosa Aquifer beneath the Savannah River Plant and vicinity. However, for this EIS, a flux of 51 cubic meters per minute is conservatively chosen (the lower bound estimate of Marine and Routt). This conservative flux better reflects the fact that Tuscaloosa heads have declined since the study was performed in 1974.

For this EIS, drawdowns of water levels in the Tuscaloosa Aquifer were calculated using the procedure for a leaky artesian aquifer (Siple, 1967). The recommended drawdown-versus-distance curve was used in this analysis. Chapters 4 and 5 describe the onsite and offsite effects in the study area shown in Figure F-32.

Figure F-27 shows the hydrographs of five Tuscaloosa wells. The location of these wells except for AK-183 is shown in Figure F-9. Well AK-183 is located 29 kilometers northwest of the center of Savannah River Plant in the Tuscaloosa outcrop area and should be uninfluenced by pumpage in the vicinity of Savannah River Plant. The winter (December to February) precipitation is plotted at the top of Figure F-27 because ordinarily, it is the precipitation in this period, which is not intercepted by growing plants, that recharges the ground water. However, abundant precipitation of about twice the annual mean caused recharge during the summer of 1964. Thus, as a result, record high-water levels occurred in 1965 and 1966. A low in winter precipitation occurred in 1968, and this resulted in low-water levels in 1970. Generally high Tuscaloosa water levels occurred in 1974, but from that point on, to the present, Tuscaloosa water levels have declined. From 1972 to 1981 there has been a general decline in the winter precipitation that may partially account for the declining water levels. However, since 1975, SRP pumping has increased by about 80 percent, from 14.9 to 27.0 cubic meters per minute in 1983. Calculations show that the decline in water levels exhibited at monitoring wells P7A, P54, and P3A is related primarily to increased ground-water withdrawal at SRP. The drawdowns at these monitoring wells reflect adjustments in equilibrium levels rather than aquifer depletion. Near-equilibrium water levels are expected to occur quickly (within about 100 days) in response to changes in pumping rates (Mayer et al., 1973).

The current total pumpage from the Tuscaloosa Formation within 32 kilometers of the Savannah River Plant is estimated to be 63 cubic meters per minute in 1983, including pumpage from wells outside the area used by Marine and Routt (1975) to estimate the flux in the Tuscaloosa Formation (see Figures F-25 and F-31). This total should not be sufficient to exceed the ground-water flux through the area as determined by the computer model. However, the incremental pumpage might be sufficient to affect local water levels as new equilibrium piezometric surfaces are attained. Siple (1967) suggested that pumpage from the Tuscaloosa at Savannah River Plant could exceed 37.8 cubic meters per minute if wells were drilled and spaced to minimize interference between wells. Current (1983) usage at SRP is about 27.0 cubic meters per minute.

The decline of water levels in the Tuscaloosa Formation since the mid-1970s has reduced but not eliminated the head reversal at the Congaree Formation that occurs southeast of Upper Three Runs. The map of the head difference between the Tuscaloosa and Congaree Formations at Savannah River Plant (Figure F-30) shows that in 1982 the head reversal was still a general situation in the Savannah and Upper Three Runs Creek valleys.

To illustrate the present vertical head relationship in the central part of Savannah River Plant, Figure F-33 repeats Figure F-5, which shows water levels in 1972, but with the addition of water levels measured November 7, 1982. Heads in the Barnwell, McBean, and Congaree are from 1 to 1.5 meters below the level of 1972, but the Tuscaloosa water levels are 3 to 3.5 meters lower. Even though the head reversal at the Congaree is still present, it is reduced. Farther southeast, the current head reversal is about 7.9 meters as shown in Figure F-10 (compare Well VSC 2 to Well VSC 3).

F.4.3 Water-level depression around water supply wells

To pump water from an aquifer, the water level in the vicinity of the well must be depressed. The amount of head depression to obtain a given pumping rate is dependent on the transmissivity of the aquifer. The transmissivity of the Tuscaloosa is very high as shown in Table F-3. Thus the cones of depression at the pumping centers for the Tuscaloosa are not very deep. Drawdowns at most 5000 cubic-meter-per-day wells in the Tuscaloosa are between 6 and 12 meters. Although specific measurement of the radii of the cones of depression have not been made at every pumping center, that these cones are not extensive is shown by the facts that when Well 20A, near M-Area (see Figure F-37), was pumped at 4900 cubic meters per day only 0.3 meter of drawdown was recorded 490 meters away and that a 5000 cubic-meters-per-day well in H-Area made a drawdown change of about 0.3 meter 700 meters away during short-term tests.

During a 60-day pumping test performed at the Barnwell Nuclear Fuel Plant (Mayer et al., 1973), water was withdrawn from the Tuscaloosa Aquifer at a rate of 10,900 cubic meters per day. A drawdown of about 0.15 meter was observed at SRP monitoring well P54 (see Figure F-9), about 9 kilometers from the pumping well. TC

Even though these cones of water level depression are not areally extensive, drawdowns of 6 to 12 meters are adequate to negate the head reversal between the Congaree and Tuscaloosa Formation where it exists. In areas where the head reversal does not exist, such as M-Area, the drawdowns increase the natural downward gradient in the area immediately surrounding the pumping wells. Because the cones of depression are not areally extensive, they probably have little hydrologic influence over waste facilities that are even moderate distances (kilometers) from the center of pumpage such as seepage basins and waste pits.

F.4.4 Effects of L-Reactor operation

As shown on Table F-10 in 1982 the pumpage at L-Area averaged only about 0.28 cubic meter per minute. When L-Area is operating, the pumping rate will be about 0.94 cubic meter per minute, slightly less than at the other operating reactors because there is no powerhouse located in L-Area. On two tests of pumping 2.8 cubic meters per minute one well (104L) had a drawdown of 8.2 meters and the other well (105L) had a drawdown of 12.2 meters; thus the average specific capacity is 0.27 cubic meter per minute per meter of drawdown. Thus, for a pumping rate of 0.94 cubic meter per minute a short-term drawdown of 3.5 meters would be expected in the pumping well (including well entrance losses). Calculated drawdowns in L-Area and in other SRP areas supporting L-Reactor operation are discussed in Sections 4.1.1.3, 5.1.1.4, and 5.2.3.

F.5 GROUND-WATER QUALITY

F.5.1 Natural ground-water quality

A detailed discussion of the natural ground-water quality of the hydrostratigraphic units is contained in previous sections of this appendix (F.2.1 to F.2.10). Chemical analyses are given in Tables F-2, F-4, and F-5. In general, the water in the coastal plain sediments is of good quality, suitable for industrial and municipal use with minimal treatment. It is generally soft, slightly acidic, and low in dissolved and suspended solids.

F.5.2 L-Area

Previous activities in L-Area have resulted in the discharge of radioactive and nonradioactive wastes into 10 basins and pits in and adjacent to the area. Currently only one of these sites is active (a rubble pit receiving solid waste that is neither radioactive nor hazardous).

Some contamination of the shallow ground water between the L-Area seepage basin and Steel Creek (about 600 meters to the southeast) is expected from the tritium previously discharged to the basin (about 3300 curies). Similarly minor amounts of strontium-90 are expected to have reached the ground water beneath the basin, but confirmation is presently lacking. Monitoring data from around the basin are not yet available; however, monitoring wells have recently been installed.

F.5.3 F- and H-Area seepage basins

Intensive ground-water monitoring studies around the F- and H-Area seepage basins have detected only tritium, strontium-90, and uranium in concentrations greater than 10 times the natural background. Companion studies have shown nitrate and mercury are also present.

Approximately 30 percent of the tritium discharged to the separations areas seepage basins evaporates to the atmosphere. The remaining tritium moves rapidly to the water table (at a depth of about 3 meters in H-Area and 15 meters in F-Area), and then moves at the same velocity as the ground water. In F-Area, the average flow rate of tritium from the basins to Four Mile Creek is estimated TC to be 0.15 meter per day (a travel time of 8.9 years to move 600 meters). Approximately 40 percent of the tritium decays before emerging in Four Mile Creek. Concentrations at seepline springs range from 40 to 60 microcuries per liter.*

In H-Area, the flow rate of tritium from the seepage basins to Four Mile Creek is estimated to be 0.3 meter per day (a travel time of 1.1 to 3.8 years). Approximately 10 to 20 percent of the tritium decays before emerging in Four Mile Creek. Concentrations at the seepline springs range up to 40 microcuries per liter.

The maximum vertical penetration of tritium into the ground is about 15 to 20 meters, and throughout most of the distance from the basins to the seepline springs, the highest concentrations are 3 to 6 meters below the water table.

Strontium, unlike tritium, does not move at the same rate as ground water; its transport is retarded by the clay minerals in the Formation. Thus, it has been emerging into Four Mile Creek from F-Area only since about 1964, and from TC H-Area since 1959. The amount entering the creek annually is 2 percent of the ground-water load in F-Area and 0.19 percent of the load in H-Area. Under current conditions, F-Area is contributing about 40 times as much strontium to the creek as H-Area because of differing soil retention characteristics. Maximum concentrations of strontium-90 in ground water and emergent seep-lines range up to 0.34 microcurie per liter in F-Area, and 1.8×10^{-3} microcurie per liter in H-Area.

Cesium is retained well by soils at Savannah River Plant, and none has migrated far enough to be detected in ground water between the separations areas seepage basins and Four Mile Creek. Alpha activity in ground water between the F- and H-Area basins and Four Mile Creek is attributed mostly to uranium discharged to the basin plus a small amount of natural radioactivity (plutonium is even more highly immobilized in SRP soils than cesium). Alpha concentrations in ground water and seepline springs range up to 6.5×10^{-3} microcurie per liter in F-Area and 7.5×10^{-6} microcurie per liter in H-Area.

Although most of the mercury released to the separations areas seepage basins is accounted for in the basin soil, studies made in 1971 on soils from the swampy outcrop along Four Mile Creek, bottom sediments, and of suspended solids from the creek show that mercury is slowly migrating into the creek (approximately 0.4 gram per day from both areas).

Nitrate and hydrogen ions are also migrating from the basins. Nitrate concentrations in the ground water measured in 1968 and 1969 ranged to 300 milligrams per liter in F- and H-Area. The pH of ground water in the vicinity of the

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*The EPA drinking water standard for tritium is 0.02 microcurie per liter.

basins is 4 to 6 compared to a pH range of 5 to 7 for natural ground water at Savannah River Plant.

Results of 1982 chemical analyses of ground-water samples from monitoring wells at F- and H-Area seepage basins are presented in Tables F-12 and F-13. The locations of these wells are shown in Figure F-34. TC

F.5.4 M-Area

The M-Area settling basin was constructed in 1958 to settle out and contain uranium discharged in process streams from fuel fabrication facilities. The water discharged to the basin can best be characterized as a metal finishing-type process waste. The process discharges contain, among other things, uranium, aluminum, nitrate, nickel, and chlorinated organics; they can be classified as hazardous only because of the low pH. Waste effluents from M-Area operations have been drained to two process sewers. In May 1982 discharges to Tims Branch were discontinued and diverted instead to the M-Area basin, which now receives all process sewer flows except noncontact cooling water. Some of the process water released to this basin seeps into the ground, but most overflows the basin and seeps into the ground at Lost Lake (shown in Figure F-35). EN-51

Extensive ground-water monitoring studies around M-Area have been conducted since volatile organics were discovered in the ground water beneath the M-Area basin in June 1981. The distribution of contaminants has been vertically and horizontally determined. A plume of chlorinated hydrocarbons extends about 1 kilometer southwest of the M-Area in 1983. The main body of this plume is moving slowly to the southwest (Figure F-35) at about 7.6 meters per year. Those studies establish that no volatile organics have migrated to the Plant boundary.

Contaminants in the soil beneath the M-Area basin have been characterized by the analyses of cores from coreholes drilled to a depth of about 5 meters below the bottom of the basin. Soil concentrations of lead and mercury ranged up to 125 and 0.16 milligram per kilogram (dry weight), respectively. In all cores, metal concentrations decreased with increasing depth beneath the basin and reached background values in the soil cores at or before 4 feet below the bottom of the basin.

Downward migration rates for metals were calculated using the corresponding depths at which the metal concentrations were equal to background values and a 24-year operation period since startup of the basin in 1958. The calculated migration rates were 0.04 meter per year for lead and 0.05 meter per year for uranium. At these migration rates and under the present operating conditions of the basin, these metals do not pose a significant problem for future contamination of the surrounding ground water. At the present rate of downward movement, it will take the uranium 700 years to travel the 37-meters distance to the ground water.

Soil concentrations of 1,1,1-trichloroethane, trichloroethylene ("triclene") and tetrachloroethylene ("perclene") ranged to 11, 90, and 2000 milligrams per kilogram (dry weight), respectively. However, migration rates could not be calculated because of wide variations in concentrations across the M-Area seepage basin.

Trichloroethane, the last of the three chlorinated organics discharged to the settling basin, was detected at the 15-foot depth and is known to be present in the ground water; perclene was also detected in the bottom sections of all five cores and has been found in high concentrations in the ground water near the basin.

Figure F-35 shows the distribution of total organic degreasers in the horizontal dimension west of the M-Area settling basin and process effluent sewer. Figure F-36 shows the extent of the contamination in a vertical section. Using the contours and from the investigation of the basin and discharge pipeline, the quantity of volatile organics in the ground water in this area is estimated at about 27,000 kilograms. From soil cores an additional 24,000 kilograms is estimated to reside in the unsaturated zone beneath the surface sources of contamination. (See Du Pont 1982, for additional details.) EN-51

Tables F-14 and F-15 give analyses of other constituents in the ground water from the Tertiary aquifers in M-Area. Figure F-37 shows the locations of these monitoring wells. A high nitrate content is characteristic of the center of the organics plume and exceeds drinking water standards. Other ground-water constituents are within drinking water limits. EN-51

Wells in neighboring A-Area (Figure F-37) that draw from the Tuscaloosa Formation (especially wells 53A and 20A) were found to have small quantities of chlorinated hydrocarbons, in concentrations from a few to about 27 micrograms per liter (Du Pont, 1983; Geraghty and Miller, 1983). The entry of chlorinated hydrocarbons into these wells might have resulted from the migration of the contaminants from Tertiary (shallow) aquifers down the well annuli to the well screens, and not from any M-Area-related contamination of the Tuscaloosa that has migrated through the overlying basal Congaree and upper Ellenton clay units. This hypothesis is being investigated through geophysical examinations of old production wells and through the monitoring of the water quality of new wells. Chlorinated hydrocarbons above the limit of detection (1 microgram per liter) have not been found in recent M- and A-Area wells drilled to monitor Tuscaloosa water quality and water levels. One of these new wells is within 80 meters of the A-Area production well (53A) that exhibited the highest concentrations of chlorinated hydrocarbons. Recent analysis of water from well 53A showed no evidence of such volatile organics as chlorinated hydrocarbons (Steele, 1983). A cement bond log of well 53A indicated extensive areas where the cement sheath around the casing was not bound to the casing. Such areas of poor bond would provide avenues for contaminated water from the Tertiary to migrate directly to the screen sections of the Tuscaloosa (Geraghty and Miller, 1983). These determinations lend support to the hypothesis that A-Area wells received contamination from ground water that entered from the shallow aquifers and not from the Tuscaloosa Aquifer. EN-51

F.5.5 Burial ground

Ground-water quality at the SRP burial ground is being extensively studied with monitoring wells located inside and adjacent to the burial site. Monitoring for radionuclides and mercury has shown that only tritium has reached the ground water in significant amounts after 30 years of operations. Average annual concentrations range up to 3300 microcuries per liter, but are typically less than 100 microcuries per liter. Traces of alpha and beta-gamma emitters have moved only short distances (up to a few hundred meters) from the point of entry.

F.6 SRP GROUND-WATER PROTECTION PLAN

The Department of Energy is committed to the protection of ground-water quality at SRP. Specifically, DOE is committed to (1) an expanded program of sitewide ground-water monitoring and study; (2) the continued involvement of the State of South Carolina in ground-water monitoring activities at and in the vicinity of SRP; and (3) taking mitigative actions at SRP to reduce pollutants released to the ground water and to establish with the State of South Carolina a mutually agreed-on compliance schedule for these actions. Current plans call for discontinuing the use of the M-Area seepage basin by April 1985 and constructing a process wastewater-treatment facility for M-Area liquid effluents (see Section 5.1.1.2). These commitments have been formalized by the Memorandum of Understanding between DOE and the State of South Carolina (Congressional Record, July 14, 1983, p. S1000) and by the FY 1984 Supplemental Appropriations Bill (Public Law 98-191, signed November 30, 1983).

A draft "SRP Groundwater Protection Implementation Plan" was developed recently (September 1983) to examine strategies and schedules to implement mitigative actions required to protect the quality of the ground waters beneath SRP. In addition to the commitment for M-Area, this sitewide plan considers other remedial actions, including discontinuing the use of seepage basins in F- and H-Areas and the continued use of the present SRP Burial Ground. It has been reviewed by the State of South Carolina and the U.S. Environmental Protection Agency--Region IV; responses to review comments are being prepared. Implementation of mitigative actions would be accomplished under DOE's Hazardous Waste and DA-2
Radioactive Mixed Waste Management Program, which is comparable to the design and performance criteria, other technical requirements, and recordkeeping and reporting requirements of the regulations (40 CFR 260-266 and 270) that EPA has adopted to implement RCRA (42 USC 6901 et seq.) (Memorandum of Understanding between DOE and EPA dated February 22, 1984). These mitigative actions would also be compatible with the State of South Carolina's hazardous waste management regulations. The draft "SRP Groundwater Protection Implementation Plan" has been incorporated in the "SR RCRA Program Management Plan" of January 23, 1984, approved by G. K. Oertel, Acting Manager. Chapter 7 contains additional information on RCRA.

The sitewide ground-water protection plan described above will be the subject of a separate NEPA review. Topics to be discussed in this review will include the sitewide use of seepage basins, disposal pits and the burial ground; mitigation and remedial measures; decommissioning of currently operating facilities receiving hazardous and radioactive mixed wastes; occupational and offsite exposures; and effects of research and development activities.

A two-volume technical document (Du Pont, 1983) supports the draft "SRP Groundwater Protection Implementation Plan." Volume I covers the site geohydrology and solid/hazardous waste; Volume II is concerned with radioactive waste at SRP. In addition, the "SRP Groundwater Protection Policy" has been approved by G. K. Oertel, Acting Manager (January 23, 1984). This policy states that:

> It is the goal of this Operations Office that all operations conducted at the SRP will not adversely affect the quality of any of the groundwater resources.
>
> - An extensive monitoring program, including sampling for both indicator and specific parameters, shall be conducted on a continuing basis.
> - All new facilities shall be designed utilizing groundwater protection concepts; new seepage basin facilities shall not be constructed.
> - All waste disposal sites on the SRP shall be fully assessed for their impacts on groundwater, utilizing an integrated, interdisciplinary approach.
> - Site utilization of groundwater resources shall be reviewed to assure compatibility with regional needs.
> - Appropriate government requirements and agencies shall be consulted where improvements in groundwater quality are desirable.
> - DA-2 Mitigative actions shall be taken, where necessary, in a timely manner to protect groundwater quality.
>
> This Operations Office will continue to cooperate with other Federal and State agencies on matters concerning groundwater protection and utilization.

In compliance with this policy, an SRP baseline hydrogeologic investigation program plan and a ground-water modeling program plan have been formulated (Bledsoe, 1984; Stephenson, 1984). Under this plan, 17 clusters of six to eight wells each will be drilled at strategic SRP locations to further define the hydrostratographic units and their geohydraulic properties. The wells will provide additional data on ground-water levels and quality for each of the major Coastal Plain hydrostratigraphic units on a sitewide basis. Information obtained from this network and from other monitoring wells will be used in computer modeling of the SRP ground-water regime.

Two other projects have been initiated recently to protect SRP ground waters. One is the design and construction of a wastewater-treatment plant to process the liquid effluent presently being discharged to the M-Area seepage basin. Treated wastewater from this plant will be discharged to an onsite stream under an NPDES permit. Current plans call for the completion of this facility by April 1985, about 6 months before the date required by the FY 1984 Supplemental Appropriations Bill (Public Law 98-181, signed November 30, 1983).

The high concentrations of chlorinated hydrocarbons found in the A- and M-Area shallow ground-water system (Tertiary ground-water system) are being removed by both a pilot and a prototype air stripper units, with capacities of

0.075 and 0.18 cubic meter per minute, respectively. Project S-2583 (Steele, 1983) will establish a 1.5-cubic-meter-per-minute production interceptor/ recovery well-air stripper system in A- and M-Areas. This system, scheduled to start operating in August 1984, has been designed to prevent chlorinated hydrocarbon contaminants in the shallow (Tertiary) M-Area ground-water system from reaching the drinking water of any offsite well or the Tuscaloosa Aquifer. Specifically, it will consist of nine 200-foot-deep interceptor/recovery (I/R) wells and an air stripper capable of removing about 30 tons of chlorinated hydrocarbons per year during the first few years of operation; thereafter, the removal rate will decrease as the concentrations of contaminants decrease. Liquid effluent from the air stripping column will either be routed to the A-Area powerhouse process-water system or used as non-process cooling water in M-Area; in either case, the wastewater would be discharged through an NPDES-permitted outfall. This I/R-well-and-air-stripping system will be constructed and operated under permits issued by the State of South Carolina. Both the EPA and SCDHEC have reviewed the initial project plans, and have agreed that the planned program is technically sound.

DOE is planning an effluent-treatment facility to treat the wastewaters that are currently discharged to the F- and H-Area seepage basins, so they can be released to an NPDES-permitted outfall. The Department of Energy will submit for approval to Congress a Fiscal Year 1986 funding request for this treatment facility; operation is scheduled for October 1988. DOE also plans to install additional monitoring wells and to take cores within the basins to provide basic data for decommissioning plans. Currently, the basins are scheduled for decommissioning by the end of 1990. DA-2

Section 4.4.3 identifies the periodic disposal of radioactively contaminated water to the L-Area seepage basin as DOE's preferred alternative for the disposal of disassembly-basin purge water. The Department will continue, however, to study and evaluate the practicability of moderator detritiation. Contingent on feasibility and approval of Congressional funding, the moderator detritiation concept will be implemented. As part of a separate NEPA review of the SRP Groundwater Protection Implementation Plan, the Department will evaluate alternative cleanup and remedial-action measures for the L-Area seepage basin.

F.7 WELL DATA FILE

In December 1983, the computerized Well Data File (WDF) at SRP contained records for 6404 wells and borings. Most of these wells are sealed and abandoned. The WDF provides a central source of information on well and boring construction, geology, and water quality. As many as 66 variables can be entered for each well. There are currently 620 monitoring wells and 70 production wells, in the WDF. The remainder are engineering and test borings, grout wells, and miscellaneous wells; this last category includes about 600 old wells, the exact location and status of which are unknown (locations are known within 100 meters). EL-25

Based on pre-SRP well-drilling practices, many of these old wells are believed to have been shallow hand-dug domestic wells. Some probably penetrated the Tuscaloosa, including some drilled flowing wells discovered on SRP in the

Savannah River valley. Any open holes, rusted-out casings, or otherwise defective wells can provide a direct route for contaminated surface water or shallow ground water to contaminate deeper aquifers, even the Tuscaloosa. Contamination of lower aquifers cannot occur from flowing wells. No hand-dug or abandoned wells are known to exist at or adjacent to either L-Reactor or any waste disposal sites of its support facilities. In addition, no contamination of the Tuscaloosa aquifer by radionuclides and chlorinated hydrocarbons has been noted in the central portion of the SRP. Abandoned well S329 in the Steel Creek floodplain, which is reported to be 20 centimeters in diameter and 33 meters deep, could be flooded if a cooling lake is selected as the alternative cooling-water system (see Section 4.4.2). This well is believed to have drawn from the *calcareous zone in the McBean Formation. Additional information on abandoned* wells is contained in Appendix L.

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Contamination of well water by chlorinated hydrocarbons (used as degreasers in M-Area) from A-Area wells producing from the Tuscaloosa was confirmed earlier in 1983. This contamination now appears to have resulted from chlorinated hydrocarbons that entered the well annuli from the contaminated shallow (Tertiary) aquifer in A- and M-Areas, and not from any generalized contamination of the Tuscaloosa aquifer itself (Geraghty and Miller, 1983).

Geophysical surveys of well 53A, which exhibited the highest contamination, indicated there were no gross casing breaks. However, packer tests indicated that the casing might leak, and a cement bond log showed that there were extensive areas where the cement sheath around the casings was not bound to the casing. Such areas of poor bond would provide avenues for contaminated water from the Tertiary to migrate directly to screened sections of the Tuscaloosa aquifer. Additional details are provided in Geraghty and Miller (1983).